NPS62-79-008

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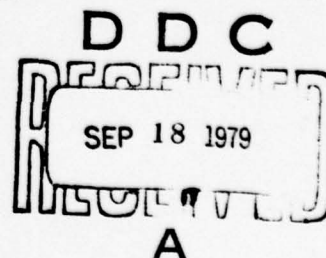## Monterey, California

DEVELOPMENT OF A REAL-TIME HYBRID
COMPUTER SIMULATION FOR THE 3K-SES,
5 DOF, DATA-BASED PROGRAM
PART I-FAMILIARIZATION AND PLANNING

Alex Gerba, Jr. and George J. Thaler

July 1979

Progress Report Period Ending
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NAVAL POSTGRADUATE SCHOOL
Monterey, California

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This report was prepared by:

ALEX GERBA, JR.
Associate Professor of
Electrical Engineering

GEORGE J. THALER
Professor of
Electrical Engineering

Reviewed by: Released by:

D. E. KIRK, Chairman   W. M. TOLLES
Department of Electrical   Dean of Research
Engineering

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Three degree of freedom approximate models have been developed for the XR-3 and the 3K-SES. Implementation in the IBM 360/67 and comparisons of turning characteristics with the 6 DOF program for the XR-3 and the 5 DOF program for the 3K-SES show good correlation. Hybrid implementation of the 3 DOF model of the XR-3 also shows good correlation. Hybrid implementation of the 3 DOF model for the 3K-SES is in progress, and extension to 5 DOF is being planned

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SUMMARY

The first step in the development of a hybrid com-
puter simulation of the data-based, 5 DOF, 3K-SES program
that will operate in real-time has been completed. A
3 DOF (Flat) turn model for an approximate and simplified
XR-3 craft was used to provide the equations of motion in
order to become familiar with 1) the turning character-
istics of the CABSES, 2) the requirements of the (NPS) NAV
PG School hybrid computer with regard to signal conversion,
timing, accuracy and loop delay due to both signal con-
version and (right-hand-side) computation and 3) the
approximate size of program that can be computed on the
existing hardware of the NPS facility.

In parallel with this investigation, the 5 DOF data-
based digital program for the 3K-SES has been converted
from CDC to IBM FORTRAN and is now operational and will
serve as the standard for evaluation of the final hybrid
simulation for the 3K-SES.

Results of the hybrid computer simulation of the 3 DOF
turn model of the XR-3 indicate that the installation of the
5 DOF program of the 3K-SES should proceed (in the next
phase) as a straight forward application of the right-hand-
side computations within the digital computer and addi-
tional degrees of freedom on the analog computer. The
successful operation of the hybrid computer simulation will

depend upon ability of the 10 year-old hardware--in
particular the digital computer--to compute the many
computational operations required for the right-hand-
side of the equations of motion in the time frame necessary
to approximate real-time manual control.

TABLE OF CONTENTS

INTRODUCTION

Reference 1 presents the Rohr Marine, Inc. analysis of the stability and maneuverability of the 3K-SES under direct manual control. The recommendations contained in Reference 1 included a suggestion to continue the investigation of manual control using a more realistic model of the response of the human operator to emergency conditions.

If a real time simulation can be developed it can provide a means of inserting an actual human operator in the loop, as well as any selected model of the operator. A hybrid realization of such a real time simulator appears to be feasible and would provide a convenient hands-on facility for a variety of human operator studies, plus many other studies in control and guidance.

This report presents the results of the first phase of a feasibility study, in which it is planned to develop a real time simulation using the NPS Hybrid Computer which consists of a CI-5000 analog unit and an XDS-9300 digital unit. The initial studies reported here are concerned with development of 3 DOF models for the XR-3 and the 3K, as a preliminary to the development of a 5 DOF Hybrid model.

II. FAMILIARIZATION AND PLANNING

IIA. THE 3 DEGREE OF FREEDOM MODEL

1. INTRODUCTION

The development of any computer model requires famili-
arity with both the system equations and the computer to be
used. In addition, one needs quantitative data to insert
the model into the computer, and one also needs typical
performance data such as experimental test results in order
to validate and verify the model. To develop a hybrid model
of the 3K-SES, we chose to start by modelling the XR-3,
because we have the required quantitative data, we have a
good 6 DOF digital program, and we have good experimental
data, plus availablility of the XR-3 craft for test as needed.
We also decided to start with a 3 DOF model, for several
reasons:

   a) It is the simplest model which will permit turning
      tests that are verifiable.

   b) The complexity of the initial model will thus be
      minimal, but we can readily add two more degrees
      of freedom with confidence in the resulting 5 DOF
      model, because the similarity of the differential
      equations will permit ready application of the
      techniques we develop in perfecting the 3 DOF model.

In addition to this decision to start with a 3 DOF model,
we chose to simplify the model by simplifying the right-hand-
side of the equations. Since the terms on the right-hand-

side are arithmetic calculations to be done in the digital unit, and because the many terms are _additive_, truncation of the right-hand-side, with simplification of the terms retained, should have little effect on results except some decrease in quantitative accuracy. This permits us to work with a less complex model in the initial stages, and addition of terms at a later point should be a simple matter. It will also have the advantage of permitting us to assess the effects of adding terms on the computational delays and on the limits of capability of our hybrid installation.

2. EQUATIONS OF MOTION OF THE 3 DOF MODEL

The three degrees of freedom to be used in this development are: SURGE, SWAY, YAW. As a result the following assumptions and approximations are needed:

1. Roll is _zero_

2. Pitch and draft remain constant

3. The origin of the ship's coordinate system is located at the center of gravity.

4. At $t = 0$ the ship coordinate system and the fixed (geographical) coordinate system have the same origin and the same coordinate axes.

5. At $t = 0$ the ship is heading in the positive X_{nav} direction.

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Figure 1. DEFINITION OF COORDINATE SYSTEMS.
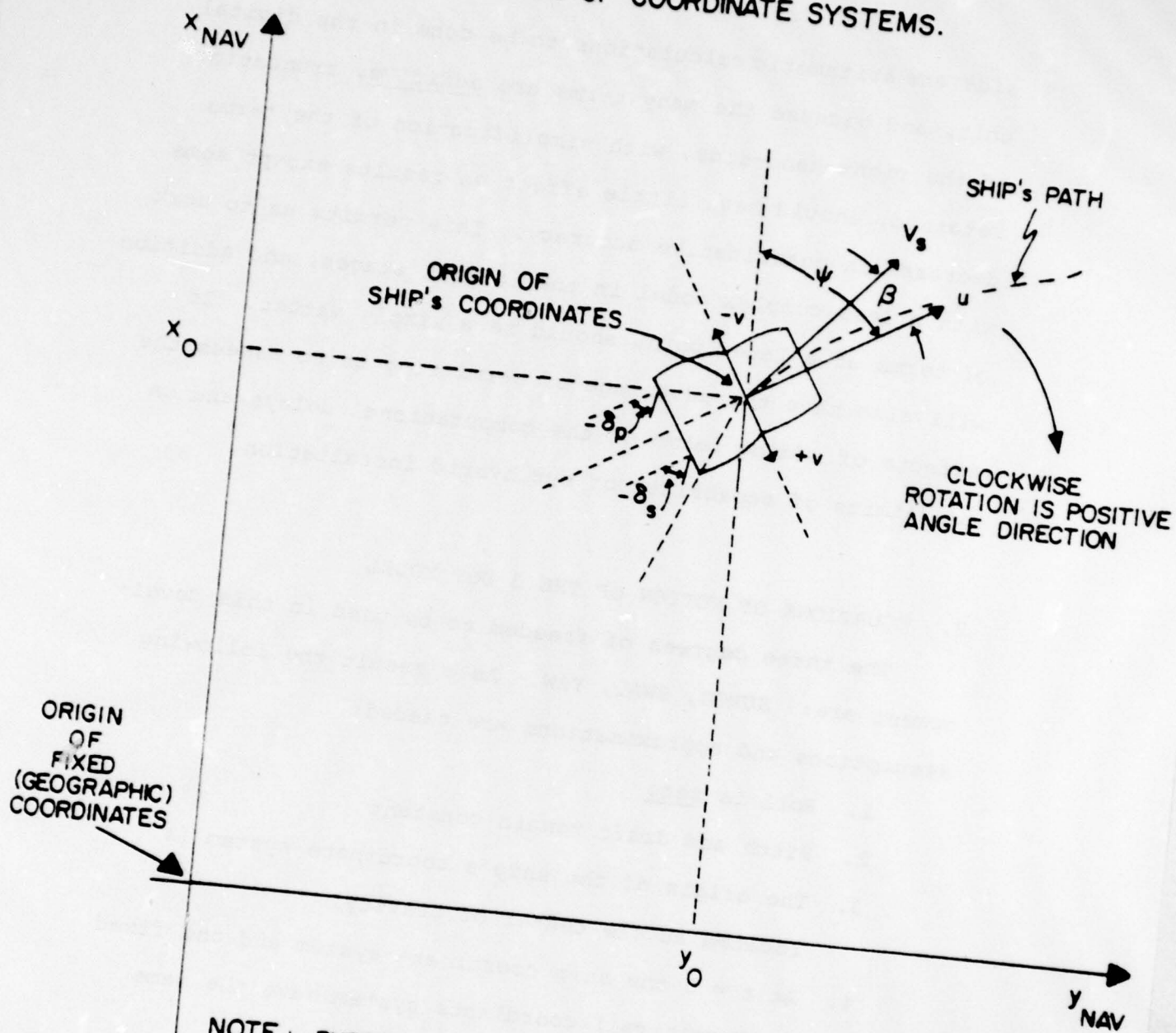
NOTE : RUDDER CONDITION FOR RIGHT TURN IS SHOWN.
ALL RUNS START AT GEOGRAPHIC ORIGIN, i.e.,
SHIP's COORDINATE ORIGIN IS LOCATED AT
GEOGRAPHIC COORDINATE ORIGIN AT $\tau = 0.0$.

The equations of motion can then be approximated by:

SURGE $\quad m(\dot{u} - vr) = X$ $\qquad$ (1)

SWAY $\quad m(\dot{v} + ur) = Y$ $\qquad$ (2)

YAW $\quad I_z \dot{r} = N$ $\qquad$ (3)

Navigation

$\dot{x}_o = u \cos \Psi - v \sin \Psi$ $\qquad$ (4)

$\dot{y}_o = u \sin \Psi + v \cos \Psi$ $\qquad$ (5)

$v_s = \sqrt{u^2 + v^2}$ $\qquad$ (6)

$\beta = \tan^{-1} \left(\frac{-v}{u} \right)$ $\qquad$ (7)

In the above equations:

m = mass of the rigid ship

I_z = moment of inertia about the z-axis

$u = v_s \cos \beta$ = velocity in the x-direction (SURGE)

$v = V_s \sin \beta$ = velocity in the y-direction (SWAY)

$r = \dot{\Psi}$ = angular velocity about the z-axis

Ψ = heading (yaw) angle (see Fig. 1)

β = drift angle (see Fig. 1)

δ = rudder angle, $+ \delta$ produces a left turn (see Fig. 1)

Also:

$x_o = \int \dot{x}_o dt$ $\qquad$ $u = \int \dot{u} dt$ $\qquad$ $r = \int \dot{r} dt$

$y_o = \int \dot{y}_o dt$ $\qquad$ $v = \int \dot{v} dt$ $\qquad$ $\Psi = \int \dot{\Psi} dt$

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The right-hand-sides (RHS) of the equations of motion have been designated X, Y, N. These symbols represent summations of forces (X,Y) and moments (N), and each summation may consist of many terms. For the initial simplified model we have discarded all terms in the summations except the few that are obviously major contributions. The terms retained are considered sufficient to produce a working simulation which should provide qualitative agreement with reference data. At a later point the model may be refined by adding terms and adjusting terms and adjusting coefficients.

After reduction of the right-hand-sides, these force summations become:

$$X = GT \cos \delta - C_{DX} u^2 \tag{8}$$

$$Y = GT \sin \delta - C_{Dy} v|v| \tag{9}$$

$$N = -(GT \sin \delta) l_o + C_{Dy} v|v| l_\omega \tag{10}$$

where: (see Fig. 2 also)

GT is the gross thrust in pounds

$\delta = \delta_s = \delta_p$ = angle of all thrust vectors

C_{DX} = coefficient of drag in the direction of surge

C_{Dy} = coefficient of drag in the direction sway

l_o (see Fig. 2) = thrust lever arm

l_ω (see Fig. 2) = sway-drag lever arm

In further explanation of equations 8, 9, 10, note that we have chosen to model the drag forces as lumped parameters acting at two points P and P' (see Fig. 2).

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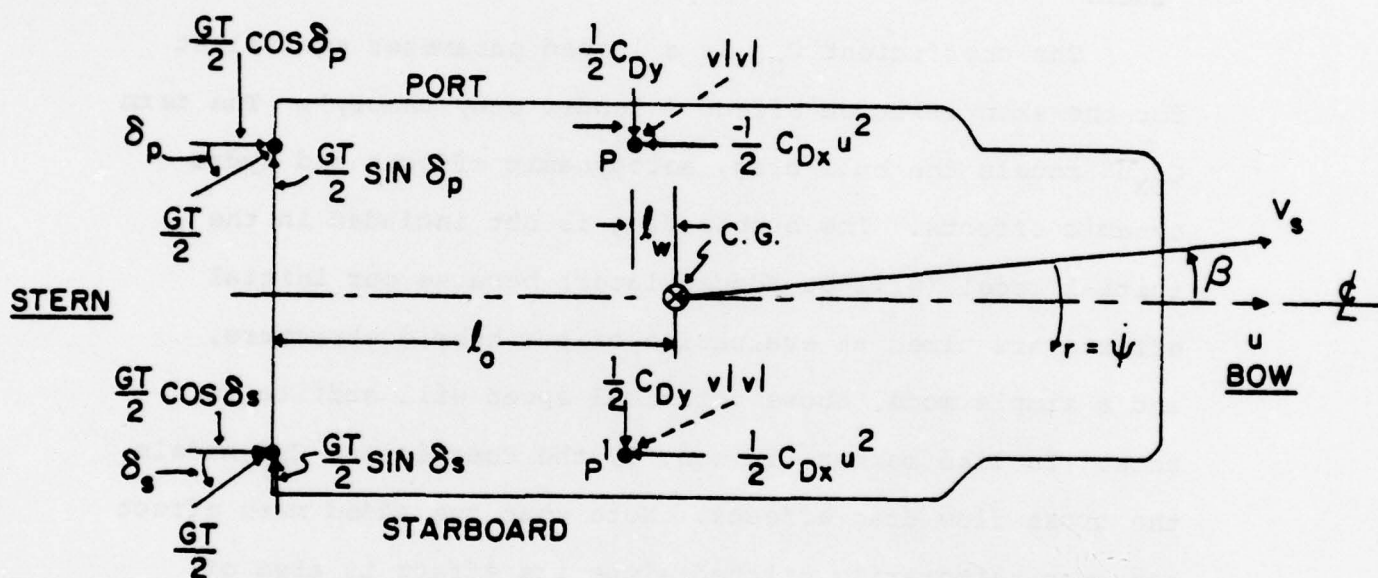
NOTE: $\delta_s = \delta_p = \delta$

P – P¹ ARE EQUIVALENT FORCE CENTROIDS

Figure 2. FORCES ACTING FOR A RIGHT TURN.

The length l_o is the distance from the stern to the center of gravity, and l_ω is the component distance (in the x-direction) from the center of gravity to the points P-P´. l_o is a fixed parameter for our initial studies (it could be changed by ship loading) but l_ω is an adjustable distance which we will use as a parameter to make the model fit test data.

The coefficient C_{DX} is a lumped parameter equivalent for the skin friction effect (slender body theory). The term $C_{DX}u^2$ models the hull drag, aerodynamic effects and hydrodynamic effects. The bubble drag is not included in the initial model (will be addded later) because our initial efforts are aimed at evaluation of our hybrid structure, and a simple model above critical speed will suffice for this. In like manner, in eqn. 9, the coefficient C_{Dy} models the cross flow drag effects. Note that the added mass effect has been temporarily omitted since its effect is also of second order.

Substituting equations 8, 9, 10 into equations 1, 2, 3 provides the basic equations of motion for the 3 degree of freedom model:

$$\dot{u} = \frac{1}{m} \left(GT \cos \delta - C_{DX}u^2 \right) + vr \tag{11}$$

$$\dot{v} = \frac{1}{m} \left(GT \sin \delta - C_{Dy}v|v| \right) - ur \tag{12}$$

$$\dot{r} = \frac{1}{I_z} \left(-(GT \sin \delta)l_o + (C_{Dy}v|v|)l_\omega \right) \tag{13}$$

Equations 11, 12, 13 are applicable to any SES craft. Selection of parameter values to be used in the equations

would depend on the particular craft, but the procedures used to identify the lumped parameter values are independent of the craft type.

3. IDENTIFICATION OF CRAFT PARAMETERS

In order to evaluate the parameters needed for the equations, the craft must be available for measurement and test (or suitable data must be available). The parameters m, I_z, l_o are constants which must be known, and GT, δ, u, v, r can be measured in steady state (if needed). Then C_{DX}, l_ω, C_{Dy} can be calculated as is shown below:

A. **Surge Drag Coefficient, C_{DX}**

The craft is run on a straight course with GT = constant and given rudder conditon δ. When steady state is reached u is measured. Then

$$\dot{u} = 0 = \frac{1}{m} (GT \cos \delta - C_{DX} u^2_{ss}) \tag{14}$$

from which

$$C_{DX} = GT \cos \delta / u^2_{ss} \tag{15}$$

where

GT = gross thrust in pounds

u_{ss} = steady state speed in feet/sec

δ = rudder angle

B. **Sway Drag Moment Arm, l_ω**

Let GT = constant and $\delta = \delta_1$, a fixed angle. When the craft reaches steady state in the turn the sway equation becomes

$$\dot{v} = 0 = \frac{1}{m}(GT \sin \delta - C_{Dy} v|v|) - ur \tag{16}$$

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from which

$$C_{Dy}v^2 = GT \sin \delta - m u r \qquad (17)$$

The steady state yaw moment equation becomes

$$\dot{r} = 0 = \frac{1}{I_z} \left[-(GT \sin \delta)l_o + (C_{Dy}v|v|)l_\omega \right] \qquad (18)$$

from which

$$C_{Dy}v^2 = (GT \sin \delta)(l_o/l_\omega) \qquad (19)$$

Combining equations 17 and 19:

$$r = \frac{GT \sin \delta (1 - l_o/l_\omega)}{mu} \qquad (20)$$

or if we wish

$$l_\omega = l_o \frac{GT \sin \delta}{GT \sin \delta - m u r} \qquad (21)$$

From Fig. 2 and eqn. 20 it is clear that the turning
rate, r, is a function of the distance l_ω, with all other
parameter values fixed. Since it is customary to command
a turning rate, if we choose r we can then evaluate l_ω. For
the XR-3, using steady state data obtained with our 6 DOF
simulation,

$$r = -0.0266(1 - 12/l_\omega) \text{ radians/sec} \qquad (22)$$

A plot of this relationsip is shown on Fig. 3.

C. Sway Drag Coefficient, C_{Dy}

Again assuming steady state conditions with fixed
thrust and fixed rudder, the sway equation, eqn. 17, provides:

$$C_{Dy} = \frac{-m u r + GT \sin \delta}{v^2} \qquad (23)$$

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Figure 3. PLOT OF RELATIONSHIP BETWEEN r AND l_w:

$$r = -.00266 \left(1 - \frac{12}{l_w}\right)$$
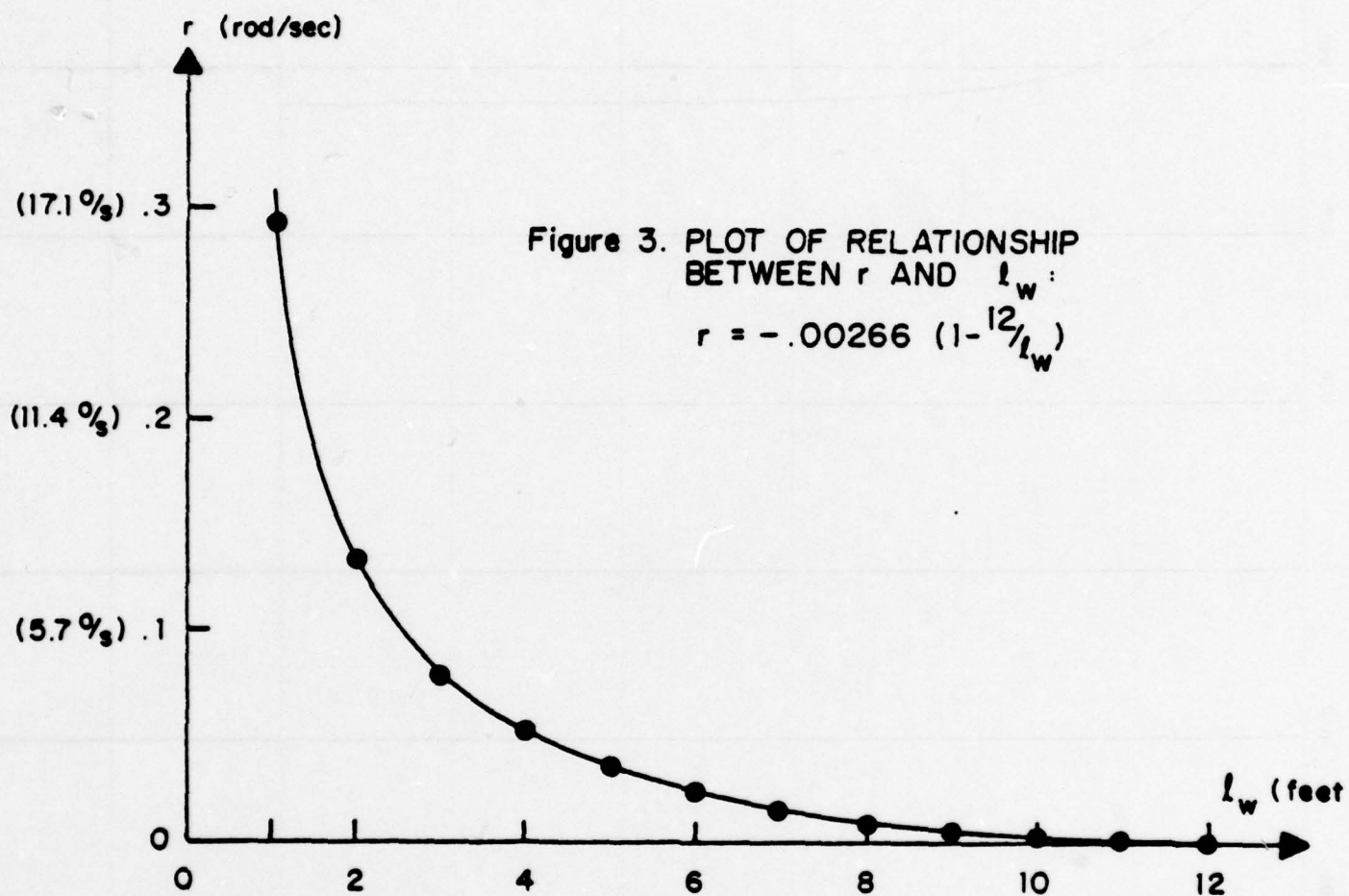
Figure 4-A. FLAT TURN DYNAMICS OF THE XR-3, PLOT OF VELOCITY vs. TIME.
r = .33 RAD/SEC (ℓ_w = 1 ft)

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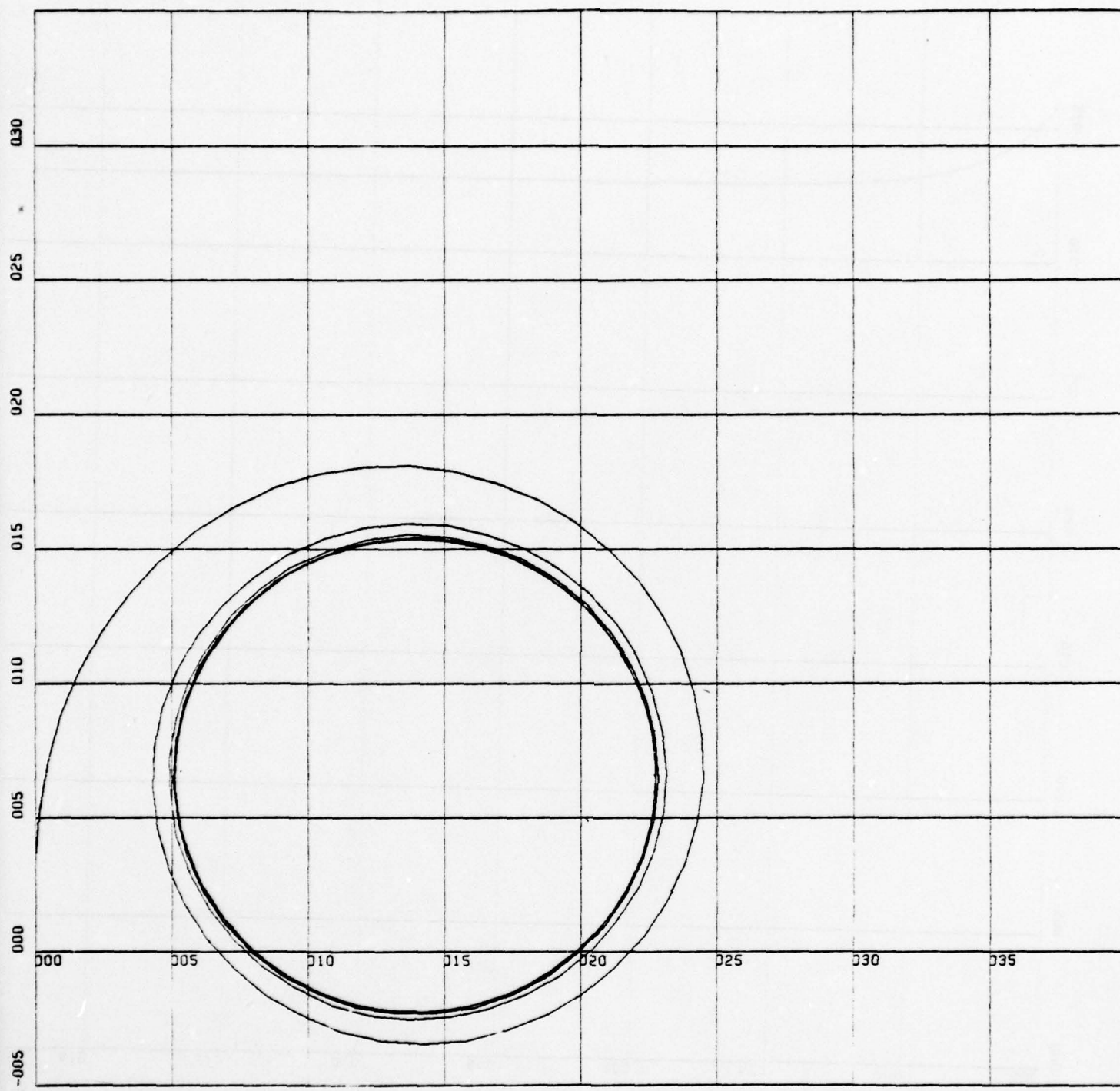
Figure 4-B FLAT TURN DYNAMICS OF THE XR-3, PLOT
OF X vs. Y.
$r = .33$ RAD/SEC ($l_w = 1$ ft)
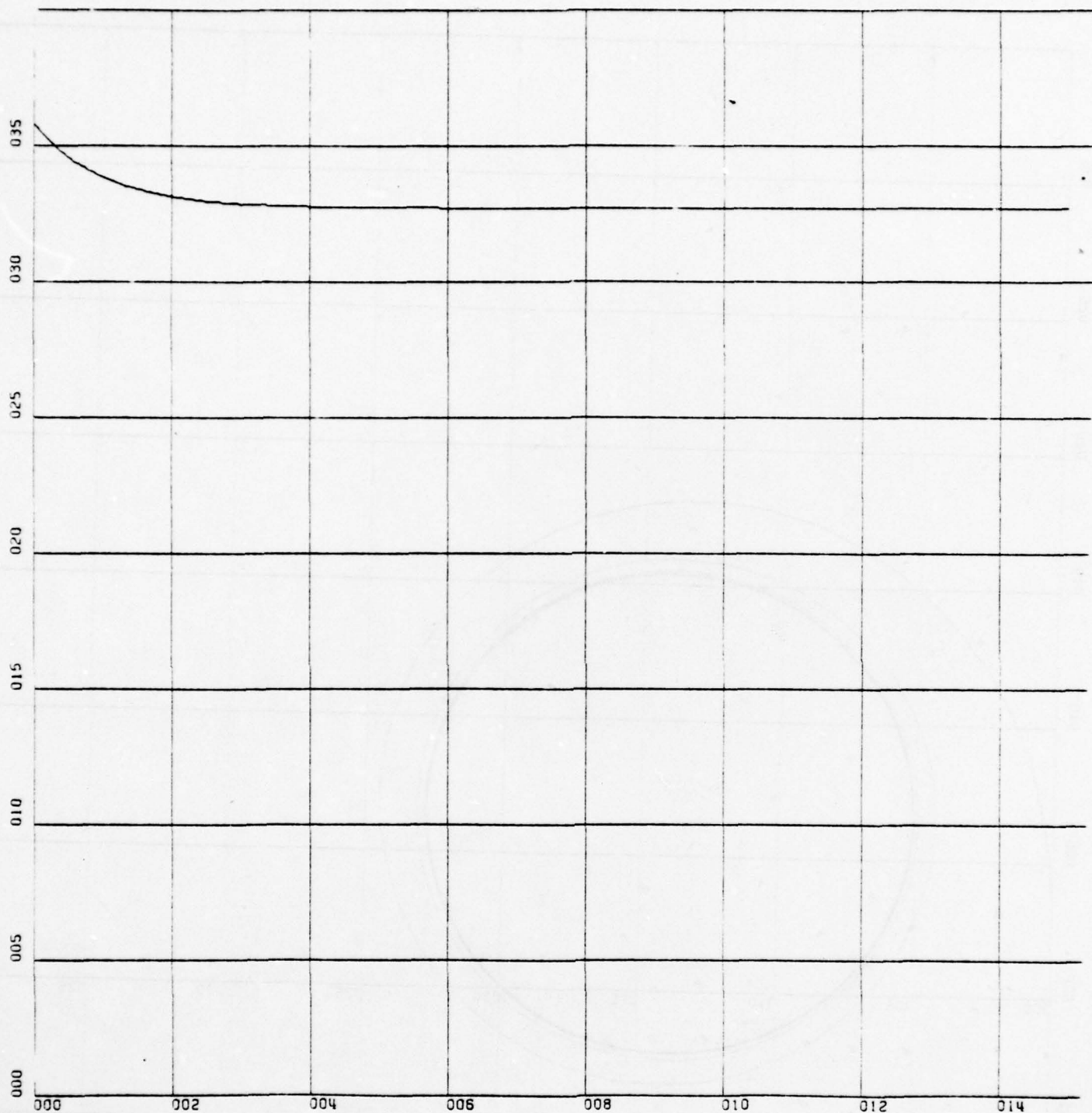
Figure 5-A. FLAT TURN DYNAMICS OF THE XR-3, PLOT
OF VELOCITY vs. TIME.
r = 0.1 RAD/SEC (ℓ_w = 2.5 ft)

22
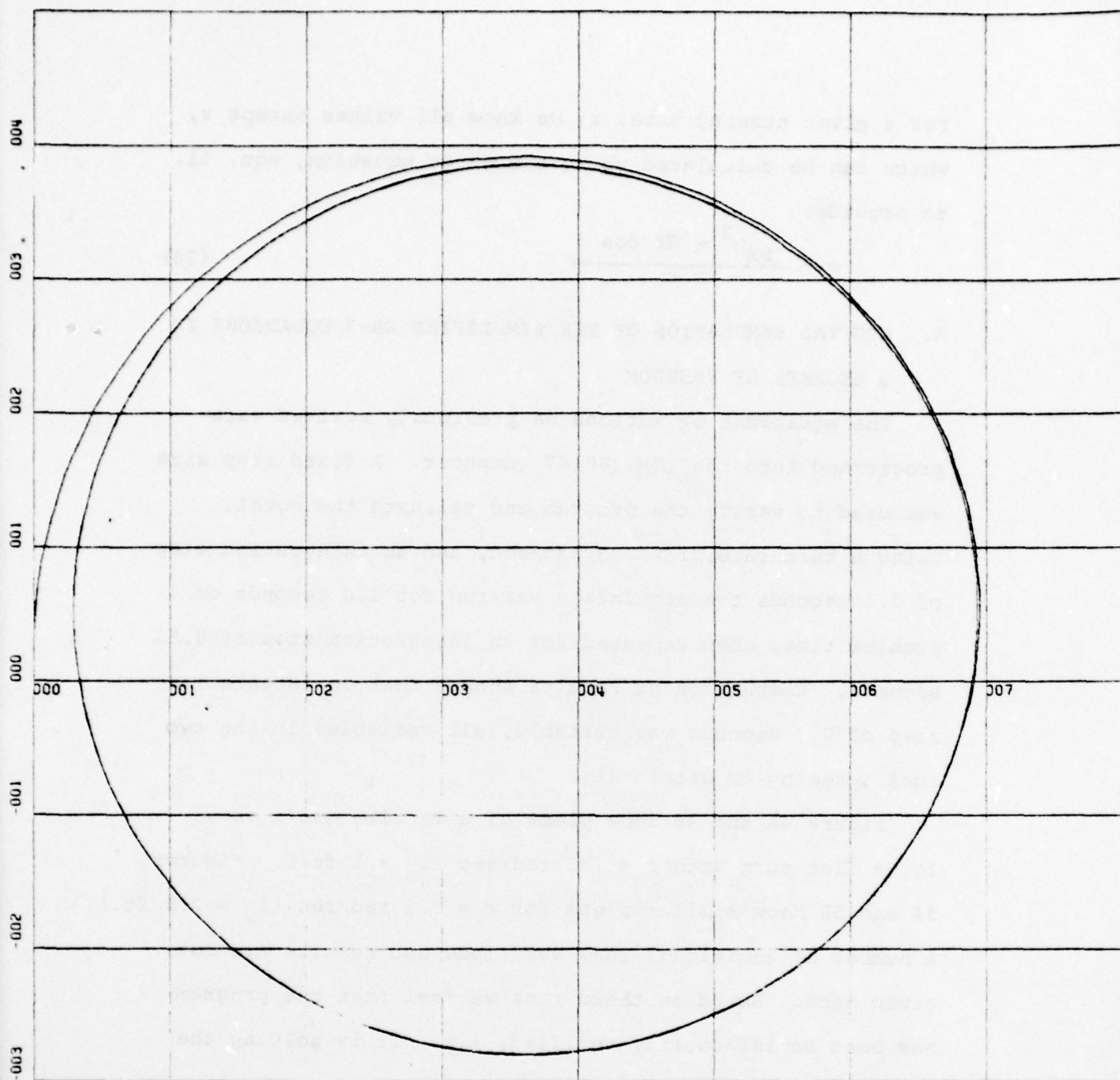
Figure 5-B FLAT TURN DYNAMICS OF THE XR-3, PLOT
OF X vs. Y.
r = 0.1 RAD/SEC (ℓ_w = 2.5 ft)

For a given turning rate, r, we know all values except v, which can be calculated using the surge equation, eqn. 11, to provide:

$$v = \frac{C_{DX}u^2 - GT \cos \delta}{m \ r} \tag{24}$$

4. DIGITAL SIMULATION OF THE SIMPLIFIED XR-3 EQUATIONS IN 3 DEGREES OF FREEDOM

The equations of motions as previously derived were programmed into the IBM 360/67 computer. A fixed step size was used to verify the program and validate the model. Using a turn rate, r = .33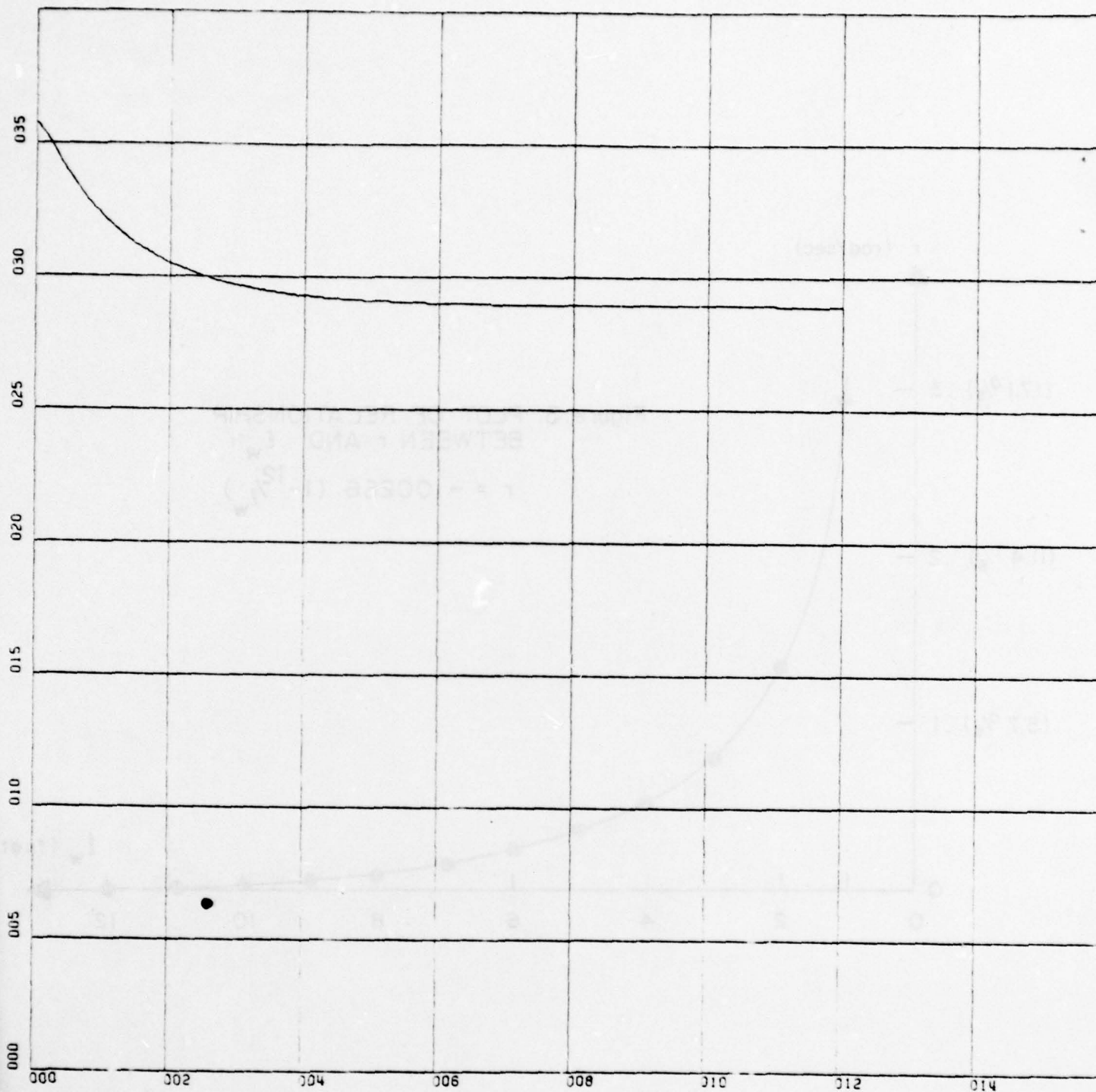 rad/sec, and an integration step of 0.1 seconds the simulation was run for 120 seconds of problem time, then repeated for an integration step of 0.01 seconds. Comparison of results showed that an integration step of 0.1 seconds was suitable, all variables in the two runs agreeing to within 1%.

Figure 4A and 4B show plots of u vs time and x vs y for a flat turn with r = .33 rad/sec (l_ω = 1 ft.). Figures 5A and 5B show similar plots for r = 0.1 rad/sec (l_ω = 2.5 ft.). A number of additional runs were made but results are not given here. Based on these runs we feel that the program has been satisfactorily verified, i.e., it is solving the equations correctly.

The following observations seem appropriate:

1. Eqn. 22 and Fig. 3 are at least qualitatively correct.

2. The effect of added mass is neglegible.

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3. We have gained confidence that, given the measured perfomance of any SES in an approximate flat turn, and given values for the parameters GT, δ, u, r, m and l_o, we can determine a value of l_ω which provides a simulation matching the measured performance reasonably closely.

4. If the simulation is performed with an initial step in the thrust angle, δ, approximate values for the system time constants can be evaluated from the resulting data. For the XR-3 operating in a flat turn the time constants are:

Variable	Time Constant
u	11.0 sec
v	0.8 sec
r	1.2 sec
β	0.9 sec

To validate the 3 DOF model, additional runs were made using the digital 6 DOF Oceanics program as modified by our NPS group for the XR-3. Also the 3 DOF model was run with 3K-SES data, and the 5 DOF model of the 3K-SES was run. For the XR-3 tests a step of rudder of 0.5 radians was suddenly applied with craft speed at 20 knots. For the 3K-SES tests and 11° rudder was applied by ramping up for 1.0 second and holding at the 11° value. Craft speed was 60 knots. Comarison of the 3 DOF, 6 DOF and 3 DOF Hybrid runs for the XR-3 is shown on Fig. 6. Correlation is not as bad as appears by inspection. Turning diameter and time for a 360° turn are almost indentical. We presently attribute the differences to the fact that the 3 DOF model does not include

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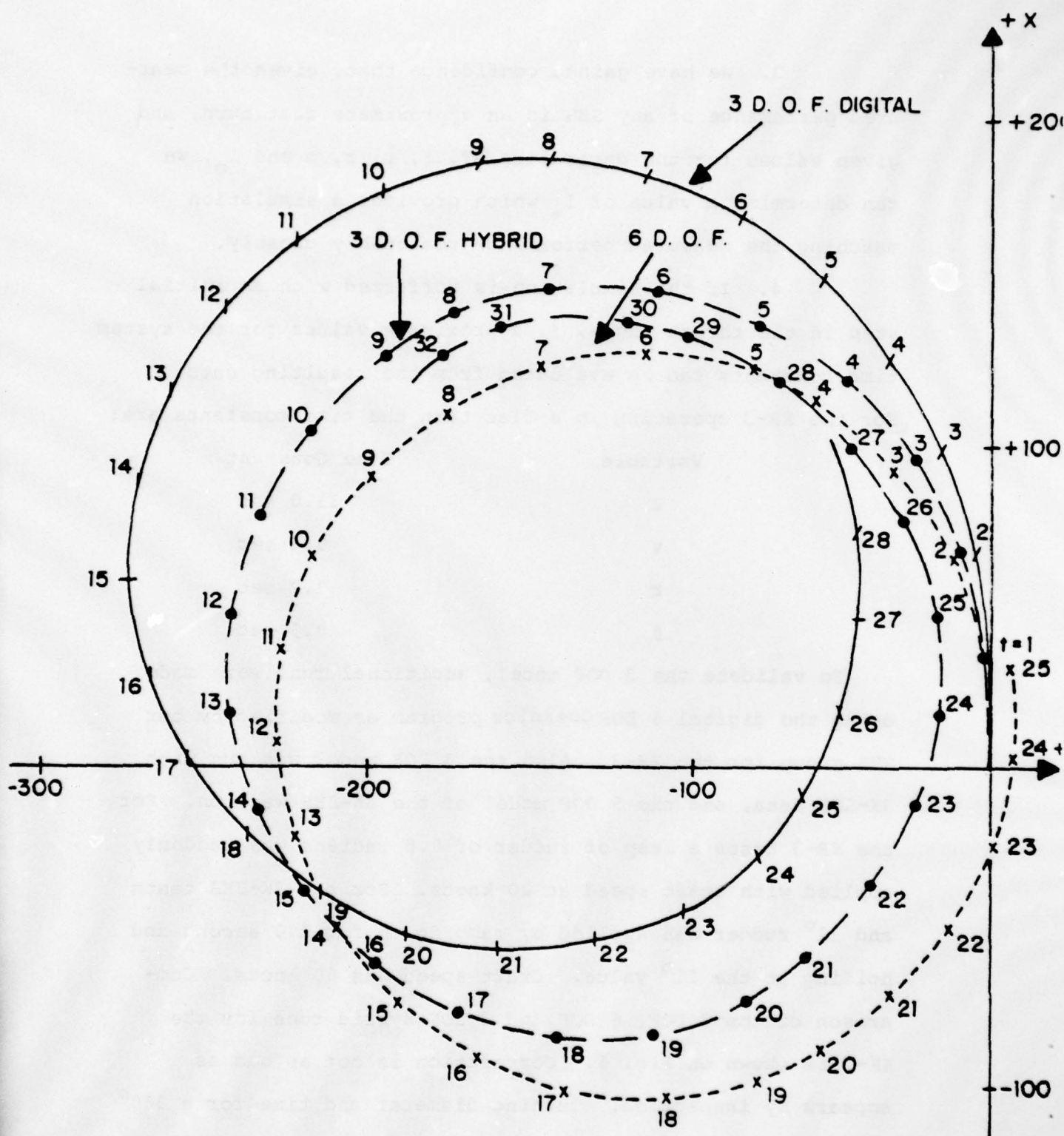
Figure 6. TURNING CHARACTERISTICS OF THE XR-3 RESPONSE TO LEFT RUDDER, 0.5 RADIAN STEP, 20 KNOTS.

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a term for bubble drag.

Figure 7 compares the 3 DOF run with the 5 DOF run for the 3K-SES. The results are almost identical, despite simplifications in the 3 DOF. This gives confidence that our modelling technique will work well when we hybridize.

5. HYBRID SIMULATION OF THE 3 DEGREE OF FREEDOM MODEL OF THE XR-3

In developing a hybrid model various arrangements and structures (programming) are possible. The philosophy chosen for our initial hybrid model is shown in the block-flow diagram of Fig. 8. Details of the programming are given in Appendix A for the simplified XR-3 model.

The simplified XR-3 model was installed in the hybrid system and tested. Comparison of results with those obtained by digital simulation showed almost identical performance, differences being less than 2%.

In developing the hybrid simulation a major concern has been the amount of time delay introduced into the loop by the A/D and D/A conversions and by the time required to perform the digital computations. We have monitored these delays in the 3 DOF model with results as follows:

1. The fundamental loop delay using D/A for $\dot{u}$, $\dot{v}$, $\dot{r}$, x, y and A/D for u, v, r was 33 ms.

2. A lower language subroutine exists, called ADDA, which can be used to replace the Fortran subroutines for A/D and D/A. This can reduce the delay by 25%.

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Figure 7. TURNING CHARACTERISTICS OF THE 3K-SES RESPONSE TO 11° LEFT RUDDER, 60 KNOTS.

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BRUSH RECORDER

(8 CHANNEL)
FOR TIME HISTORY OF $\dot{u}, \dot{v}, \dot{r}, r$

X-Y PLOTTER

FOR OUTPUT OF THE NAVIGATION VARIABLES, x, y

CT-5000

ANALOG COMPUTER FOR INTEGRATION OF $\dot{u}, \dot{v}, \dot{r}$

$\dot{u}, \dot{v}, \dot{r}$
$\bar{r}, \bar{r}$
$\bar{x}, \bar{y}$

$\bar{u}, \bar{v}$

$\overline{\dot{u}}, \overline{\dot{v}}, \overline{\dot{r}}$
$\bar{x}, \bar{y}$

$\bar{u}, \bar{v}, \bar{r}$

D/A

A/D

CONTROL PANEL

INPUT: GT, δ

$\overline{GT}, \bar{\delta}$

A/D

AGT-10

(GRAPHIC TERMINAL)
FOR:

DISPLAY (FUNDAMENTAL UNITS): $\dot{u}, \dot{v}, \dot{r}, r, u, v, r,$ $x, y, \psi.$

DISPLAY MAX AND MIN VALUES OF ABOVE VARIABLES.

DISPLAY CURRENT VALUES (CONVENTION- AL UNITS) GT, δ, DELT Te, ψ, r, β, u

GATED

CONVERSION OF UNITS FOR GRAPHICS, AND CONTROL OF GRAPHICS DIS- PLAY.

XDS-9300

(DIGITAL COMPUTER)

FOR:

INPUT DATA
INITIALIZE EQUATIONS
AND COMPUTE PARAMETERS

COMPUTE RHS VARI- ABLES FOR $\dot{u}, \dot{v}, \dot{r}$

COMPUTE NAVIGATION VARIABLES x, y, ψ

COMPUTE ELAPSED TIME, Te.

COMPUTE DELT (THE LOOP DELAY) USING INTERNAL 1 kHz CLOCK.
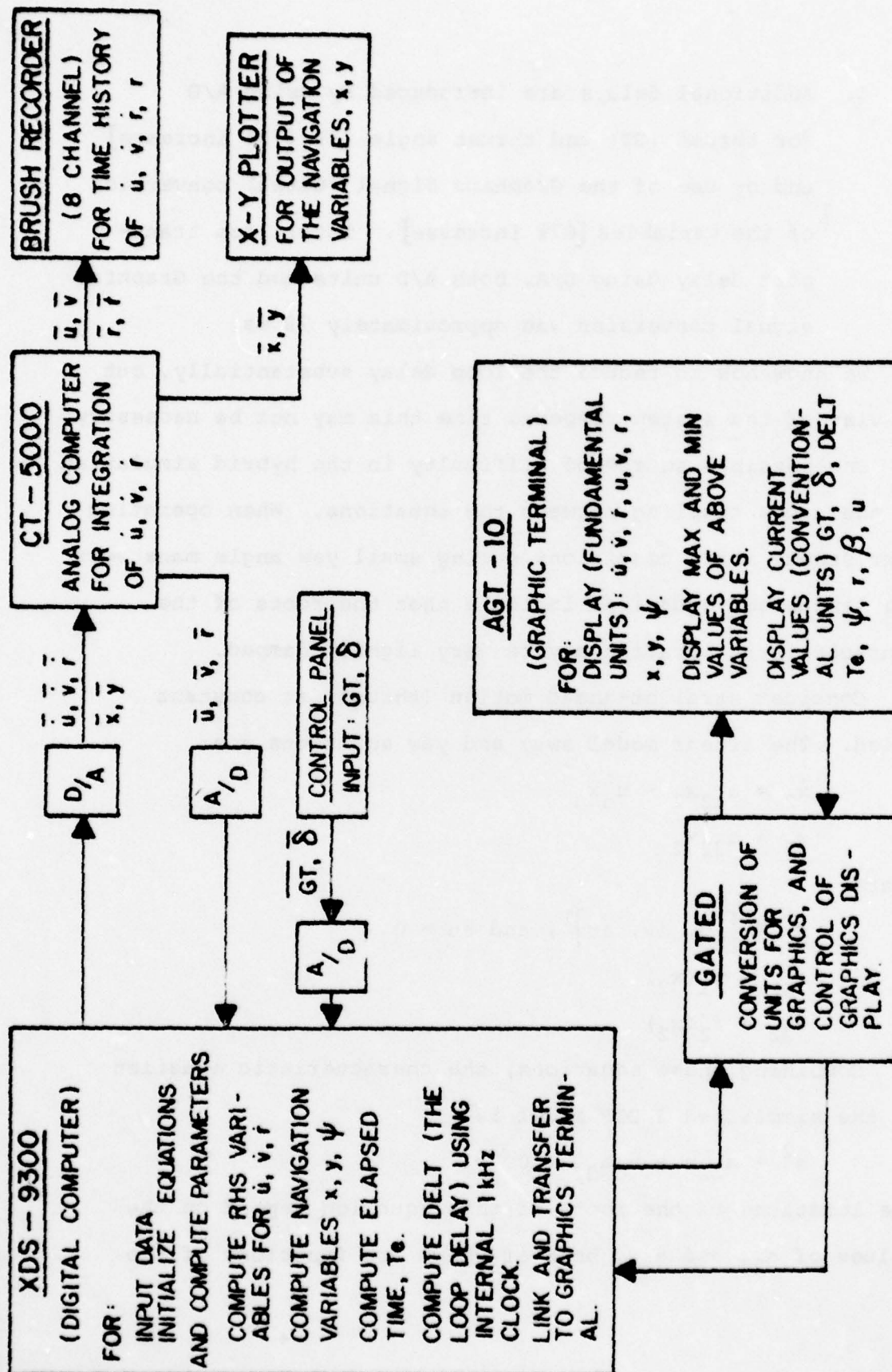
LINK AND TRANSFER TO GRAPHICS TERMIN- AL.

Figure 8. STRUCTURE FOR HYBRID SIMULATION OF 3 D.O.F. (FLAT) TURN EQUATIONS.

3. Additional delays are introduced by using A/D
    for thrust (GT) and thrust angle (δ) [76% increase]
    and by use of the Graphics Signal (Gated) conversion
    of the variables [67% increase]. Total loop trans-
    port delay using D/A, both A/D units and the Graphics
    signal conversion was approximately 78 ms.

We know how to reduce the loop delay substantially, but
in view of the system response time this may not be necessary.

One possible source of difficulty in the hybrid simulation
is the cross coupling between the equations. When operating
near steady state conditions during small yaw angle maneuvers
the linearized equations indicate that the roots of the
characteristic equation may be very lightly damped.

Consider straight-ahead motion (thrust) at constant
speed. The linear model sway and yaw equations are:

$$\dot{x}_2 = a_{22}x_2 - u_o x_3$$
$$\dot{x}_3 = a_{32}x_2$$

where

$$\underline{x}' \triangleq \left[\Delta u, \ \Delta v, \ \Delta r\right]^T, \text{ and } \Delta u = 0$$
$$a_{22} = f_1(x_2)$$
$$a_{32} = f_2(x_2)$$

Combining these equations, the characteristic equation
of the simplified 3 DOF model is

$$s^2 + a_{22}s + u_o a_{32} = 0$$

The locations of the roots of this equation depend on the
values of a_{22} and a_{32}, both of which are functions of the

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sway velocity. For small values of sway velocity the roots are complex conjugates and approach the origin of the s-plane as the sway velocity approaches zero. For larger values of sway velocity such as those encountered in a turn maneuver the roots are real and negative, providing a well damped response for yaw and sway motions. This appears to be similar to the Dutch Roll effect in aircraft.

For straight ahead runs using the digital program for the 3 DOF model and setting the initial value of v to zero, no sway-yaw motions are observed. However, if we set a small initial condition on v a transient oscillation is observed in both sway and yaw as shown on Fig. 9. This verifies the existence of the phenomenon, and we expect to encounter it in the hybrid since the equations are the same. However, in the hybrid there is a possibility that the roots may move into the right half s-plane due to either:

1. DC unbalance in the analog computer integrators, or,

2. Excessive loop delay from A/D, D/A and digital computations.

The first of these possible causes can be avoided by careful balancing of the operational amplifiers before running. The effect of the loop delays can be controlled somewhat by minimizing the number of terms requiring digital computation.

6. STATUS OF THE 3 DOF MODEL STUDIES

These appear to be both complete and successful. Both

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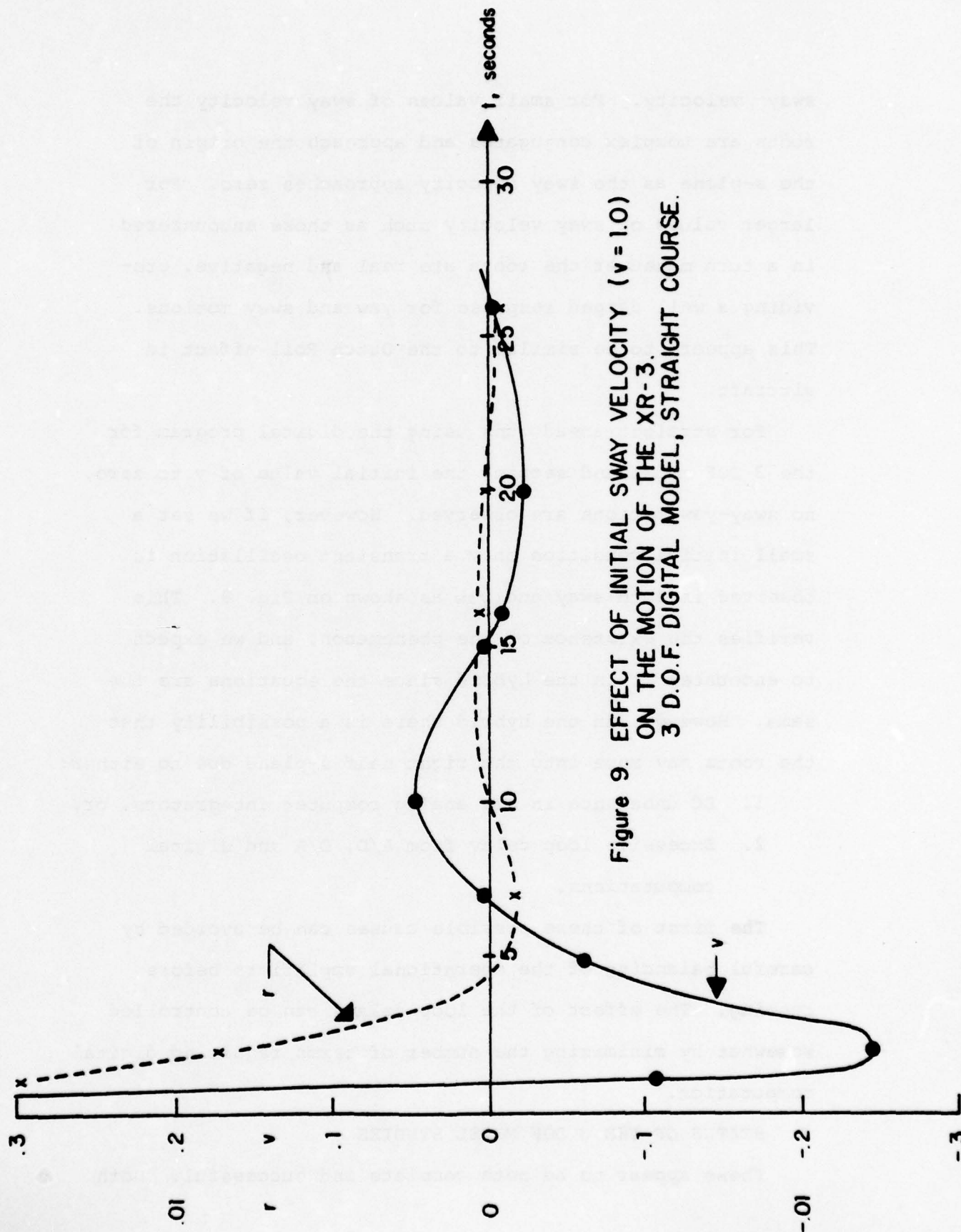
Figure 9. EFFECT OF INITIAL SWAY VELOCITY (v = 1.0) ON THE MOTION OF THE XR-3. 3 D.O.F. DIGITAL MODEL, STRAIGHT COURSE.

qualitative and quantitative agreement have been achieved
with the 5 DOF digital simulation as a reference. Future
studies will be aimed primarily at the 5 DOF model of the
3K-SES except when we wish to correlate computer data with
specially designed experiments.

IIB. THE 5 DEGREE OF FREEDOM MODEL

1. INTRODUCTION

Having developed a simplified 3 DOF model of the XR-3,
we now proceed to use the knowledge thus obtained and apply
it to the 3K-SES. We do not plan to develop a 5 DOF
hybrid model of the XR-3. Our procedure is to install
the NSRDC 5 DOF program for the 3K-SES in our IBM 360/67
computer, generate reference curves with it, obtain any
numbers we need for our 5 DOF hybrid simulation, then
verify and validate the hybrid model of the 3K-SES.

2. THE DIGITAL SIMULATION OF THE 3K-SES IN 5 DEGREES OF FREEDOM

This program was obtained from NSRDC. It has been
written for a CDC machine and had to be converted to the
IBM version of Fortran for our computer. This has been
completed, the program is operational and as far as we
know has no obvious "bugs". We are familiarizing ourselves
with the program, and exercising it to obtain data we will
need in developing the 5 DOF hybrid model, and for validating
it.

Details of the conversion-problems encountered, their
solutions, etc. are discussed in Appendix B.

3. HYBRID SIMULATION OF THE 3K-SES

This is under development at the present time. Hope-
fully we need only insert a new set of constants in the

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equations of the hybrid XR-3 model, but undoubtedly other adjustments and modifications will be needed, particularily in the trade-off of digital vs analog computation in order to perform a real-time simulation.

4. STATUS

Progress has been satisfactory. It is too early to predict future developments.

III.   SUMMARY AND CONCLUSIONS

The NPS Hybrid Computer consisting of the XDS-9300 digital and the CI 5000 analog computers has been programmed to simulate the 3 DOF Flat Turn maneuvering dynamics of the CAB type Surface Effect Ship.

The XR-3 has been programmed with simplified modelling of the drag forces and thrust-input force on the hybrid computer for simple flat turn maneuvers. An evaluation of the hybrid simulation was carried out by comparison of the time histories of the velocities and the navigation variables against those values obtained from the 3 DOF digital simulation for the same maneuvers. In addition, the XR-3 hybrid 3 DOF results were compared to the 6 DOF loads and motion output.

The result of this comparison was that the hybrid computer simulation produced a time response to a step rudder input that produced a navigational turning plot that was in-between the all digital 3 DOF and all digital 6 DOF trajectories.

Additionally the 3 DOF simplified RHS (right-hand-side) digital program was operated for the same turning conditions that was used for the 5 DOF, DBSIM5D . Program and the comparison indicates close agreement in the navigational trajectories for an 11 degree vectored thrust angle full-turn maneuver.

This feasibility study has shown that the hybrid computer implementation for the 5 DOF 3K-SES in real-time is possible with the available equipment at the NPS Computer Laboratory. Real-time computation is of course only approximated when using the hybrid computer. The loop transport delay inherent in this simulation is due to the signal conversion (A to D and D to A) and the necessary digital computation for the acceleration forces and moments. The magnitude of this delay time has a fixed minimum value as a result of signal conversion and a maximum value due to righ-hand-side calculation required for the acceleration added to the fixed time due to the signal conversion. Real-time computation accuracy is determined principally by the magnitude of this maximum value for the loop delay.

The 3K-SES was approximated with the simplified 3 DOF Flat Turn equations and the results were compared. It was shown that the full maneuvering trajectories for an 11 degree thrust angle compared very closely with the 5 DOF, DBSIM5D Program results. These results indicate that only a few terms on the RHS may be all that are required to simulate the 3K-SES for the type of maneuvering control studies to be conducted in the future on the hybrid computer.

The conclusion of this feasibility study is that successful implementation of a hybrid computer, real-time simulation of the DBSIM5D Program has a very high probability. The degree of complexity necessary for the RHS

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computation will be the limiting factor on the loop delay
that controls the real-time accuracy.

IV. LIST OF REFERENCES

1. E.H. Price, R.C. Stoner, V.L. Wener, Stability and
    Maneuverability Report, CDRL No. E03L, Document No.
    TTP0013A, Rohr Marine, Inc., Chula Vista, CA.,
    31 August 1978

APPENDIX A.   HYBRID COMPUTER PROGRAM FOR THE

3 DOF (FLAT) TURN EQUATIONS

A general schematic diagram of the hybrid structure
used is shown in Fig. A-1. The listing of the digital
program for the XDS-9300 computer is also included in this
appendix, and the analog computer connections are shown
on Fig. A-2.

As may be seen from the listing of the digital pro-
gram, the right-hand-sides (RHS) of the acceleration
equations for the 3 DOF are computed on the XDS-9300,
which also does the magnitude scaling for the analog
computer (CI-500) voltages. In addition the XDS-9300
provides the required control logic, timing and temporary
storage of computed variables.

The graphics terminal (AGT-10) provides real time
display of the desired output and control variables, as well
as their maximum and minimum values. Piloting of the craft
is carried out at the graphics terminal. Additional
permanent record outputs of navigation x and y are obtained
with an XY-pen recorder, and plots of other system variables
are obtained on an 8 channel Brush recorder.

A sample of the x-y output for the 3 DOF simplified
XR-3 craft is shown on Fig. A-3. The plot starts with a
right turn (δ = -0.5 radians) at t = 0, using a terminated
ramp input. The rudder was held at δ = -0.5 for two turns,
then reversed to δ = +0.5 for a half turn, followed by

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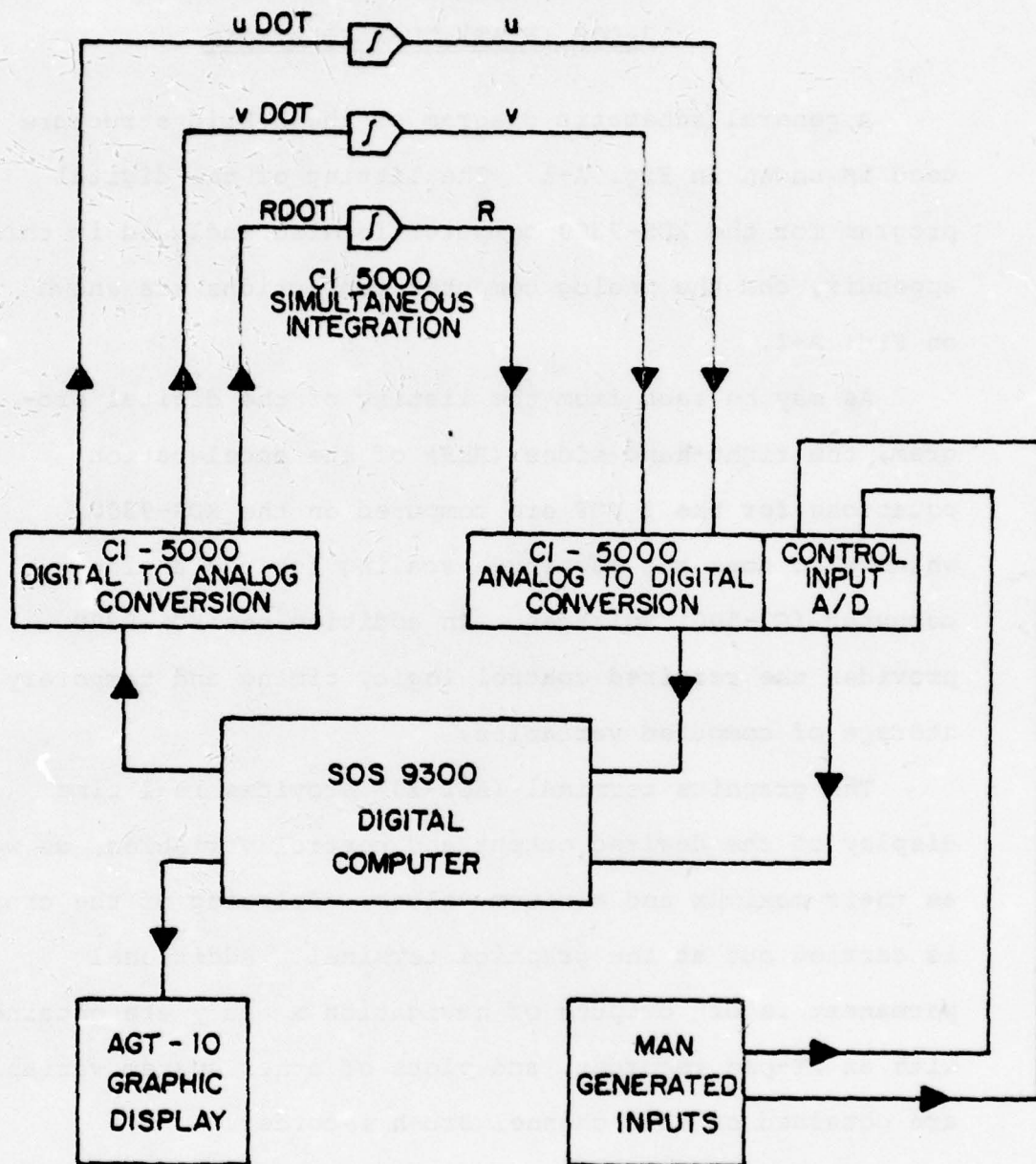
HYBRID COMPUTER

Figure A-1. BLOCK DIAGRAM OF THE HYBRID STRUCTURE.
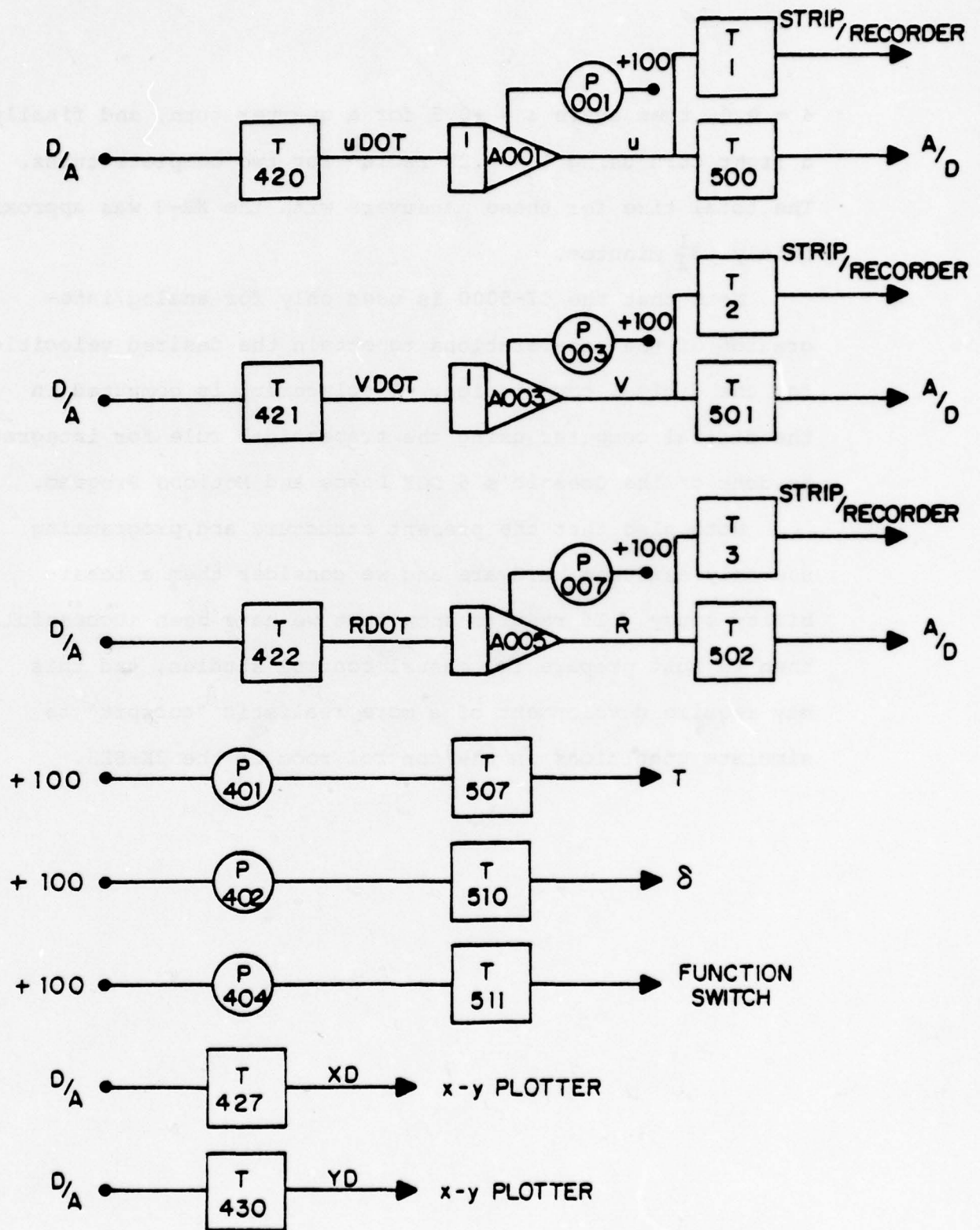
Figure A-2.   DIAGRAM OF THE ANALOG COMPUTER
CONNECTIONS.

δ = 0.0, then again δ = +0.5 for a quarter turn, and finally a right turn using δ = -.29 radian for two complete turns. The total time for these maneuvers with the XR-3 was approximately $3\frac{1}{2}$ minutes.

Note that the CI-5000 is used only for analog integration of the accelerations to obtain the desired velocities for the digital computation. Displacement is computed in the digital computer using the trapezoidal rule for integration as done on the Oceanic's 6 DOF Loads and Motions Program.

Note also that the present structure and programming use only existing hardware and we consider them a feasibility study. If results show that we have been successful, then we must prepare for manual control studies, and this may require development of a more realistic "cockpit" to simulate conditions in the control room of the 3K-SES.

Figure A-3. SAMPLE OF THE HYBRID
OUTPUT x-y PLOT FOR
THE 3 D.O.F. XR-3

t₀
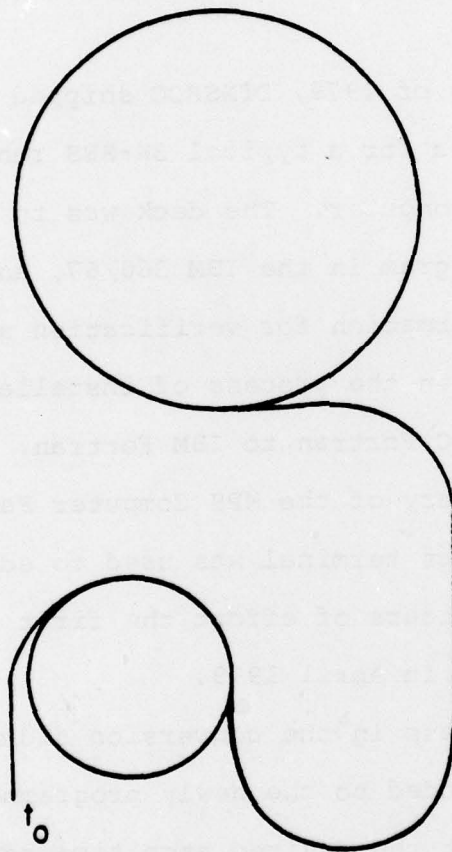
APPENDIX B. <u>INSTALLATION OF THE 3K-SES, 5 DOF</u>

<u>PROGRAM IN THE IBM 360/67 COMPUTER</u>

In the fall of 1978 the 3K-SES, 5 DOF data based
program called DBSIM5D was delivered to the Naval Post-
graduate School, at which time a commitment was made by
the NPS group to attempt a hybrid computer simulation based
on this program.

In the spring of 1979, DTNSRDC shipped the card deck
and the output data for a typical 3K-SES run, obtained by
DTNSRDC on a CDC computer. The deck was to be used in
installing the program in the IBM 360/67, and the output
data provided information for verification and validation.
The major problem in the process of installation was the
conversion from CDC Fortran to IBM Fortran. With the help
of Mr. Roger Hilleary of the NPS Computer Facility, the
interactive graphics terminal was used to edit the program.
After some 50 man hours of effort the first successful
batch run was made in April 1979.

Complete success in the conversion did not occur until
a correction was added to the newly programmed TIMER, to
allow for a stop at the desired stop time rather than a
premature stop time due to the timer program.

To validate the IBM version of the program we dupli-
cated the sample run for the 3K-SES. This run, as provided
by DTNSRDC, was for a left turn, using an 11 degree effector
angle and a speed of 60 knots. The sample run terminated
after 14.5 seconds of real (problem) time. The 11 degree

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effector angle was programmed as a ramp which terminated after 1 second, and remained constant at 11 degrees for an additional 50 seconds.

A comparison of the output of the IBM 360/67 version with the sample run data from the CDC computer showed that the recorded variables were in complete agreement within the accuracy differences of the two computer word length.

The problems of conversion were simple but time consuming and may be listed as follows:

1. 6 character variable name limit on the IBM computer as compared with a 7 character limit on the CDC.

2. Single statement limit on the IBM computer versus multiple statement on a single card for the CDC.

3. Identification of temporary files used for the output data.

4. Identification of the timing control and programming the IBM computer timer to provide the functions required for operation of the program.

5. Addition of the proper job control language (JCL) cards to compile, link and compute.

```
 1:        DIMENSION ITEXT(29),ILAP(24),POTS(24),POTK(24),IMAGE(3000)
 2:       C,IL(24),TITLE(24),AD(10),AA(12),ILA1(24),ILA2(24),ILA3(24),
 3:       CILA4(24),ILA5(24),ILA6(24),ILA7(24),ILA8(24),IPLOT(10),IVIEWA(20),
 4:       CIVIEWB(20)
 5:        EQUIVALENCE (AD(1),A11),(AD(2),A21),(AD(3),A31),(AA(1),B11),
 6:       C(AA(2),B21),(AA(3),B31),(AA(4),B41),(AA(5),B51),(AA(6),B55),
 7:       C(AA(7),B61),(AA(8),B71),(AA(9),B81),(AA(10),B91),(AA(11),B101),
 8:       C(AA(12),B111),(AD(4),A41),(AD(5),A51),(AD(6),A61),
 9:       C(AD(7),A71),(AD(8),A81),(AD(9),A91),(AD(10),A101)
10:        CALL DAL(.0,.0,.0,.0,.0,.0,.0,.0,.0,.0,.0,.0)
11:        CALL SETPOT(4HP001,.0,4HP003,.0,4HP005,.0,4HP007,.0,4HP011,.0,
12:       C4HP015,.0)
13:        CALL RESET(1000)
14:        CALL COMPUTE
15:        CALL DGINIT(2,IVIEWA,20,IER)
16:        CALL DGINIT(2,IVIEWB,20,IER)
17:        CALL DGINIT(2,IPLOT,10,IER)
18:        CALL DTINIT(1,ITEXT,29,IER)
19:        ENCODE(96,1,TITLE0)
20:  1     FORMAT('          REAL TIME          ')
21:        CALL TEXT8(1,TITLE0,24,6,1,3,3,IER)
22:        ENCODE(96,2,TITLE1)
23:  2     FORMAT('   MOTION ANALYSIS PROGRAM     ')
24:        CALL TEXT8(1,TITLE1,24,9,1,3,3,IER)
25:        I=1000000
26:        CALL DELAY
27:        IVIEWB(1)=IHEAD(1,10)
28:        IVIEWB(2)=IPACK(0.0,1.0,0)
29:        IVIEWB(3)=IPACK(0.0,0.5,1)
30:        IVIEWB(4)=IPACK(-1.0,0.0,0)
31:        IVIEWB(5)=IPACK(-0.5,0.0,1)
32:        IVIEWB(6)=IPACK(0.5,0.0,0)
33:        IVIEWB(7)=IPACK(1.0,0.0,1)
34:        IVIEWB(8)=IPACK(0.75,1.0,0)
35:        IVIEWB(9)=IPACK(0.75,0.5,1)
36:        IVIEWB(10)=IPACK(0.5,0.75,0)
37:        IVIEWB(11)=IPACK(1.0,0.75,1)
38:        IVIEWB(12)=0
39:        CALL GRAPH8(2,IVIEWB,12,1,IER)
40:        IPR=0
41:        ICOA=0
42:        ICO=0
43:        NDA=12
44:        NAD=10
45:        IN=0
46:        X=-100.
47:        TIME=0.0
48:        AAAA=0.
49:        P=0.0
50:        G=0.0
51:        RHO=2.0
```

```
52:        G=32.2
53:        M=180.
54:        CDX=.3
55:        CDY=1555.0·
56:        LW=1.0
57:        L9=10.
58:        J=1
59:        IZ=3333.
60:        A22=1.0
61:        AU=.45
62:        AUDOT=.45
63:        AV=.020
64:        AVDOT=.020
65:        AR=0.0100
66:        ARDOT=0.0100
67:        AXO=25.
68:        AYO=25.
69:        AT=3.75
70:        AZ=.005
71:        IOG=0
72:        TX=0.0
73:        TY=-6000.
74: 650 CALL OTINIT(1,ITEXT,29,IER)
75: 501 FORMAT('PRESENT',2F10.2,'           ',F4.2,'    ',F8.2,'              ',F6.3,
76:     C'        ',F6.3)
77: 525 FORMAT('MAXIMUM',2F10.2,'           ',F4.2,'    ',F8.2,'              ',F6.3,
78:     C'        ',F6.3)
79: 526 FORMAT('MINIMUM',2F10.2,'           ',F4.2,'    ',F8.2,'              ',F6.3,
80:     C'        ',F6.3)
81: 507 FORMAT('PRESENT',F8.2,F10.3,'            ',F4.2,' ',F8.3,'            ',
82:     CF5.3,'        ',F6.3)
83: 527 FORMAT('MAXIMUM',F8.2,F10.3,'            ',F4.2,' ',F8.3,'            ',
84:     CF5.3,'        ',F5.3)
85: 528 FORMAT('MINIMUM',F8.2,F10.3,'            ',F4.2,' ',F8.3,'            ',
86:     CF5.3,'        ',F5.3)
87: 511 FORMAT('PRESENT',F7.3,F10.3,'       ',F10.2,'     ',F8.3,'         ',F6.3,'
88:     C    ',F6.3)
89: 529 FORMAT('MAXIMUM',F7.3,F10.3,'       ',F10.2,'     ',F8.3,'         ',F6.3,'
90:     C    ',F6.3)
91: 530 FORMAT('MINIMUM',F7.3,F10.3,'       ',F10.2,'     ',F8.3,'         ',F6.3,'
92:     C    ',F6.3)
93: 516 FORMAT(F6.2,'     ',F4.2,'           ',F4.3,'    ',F6.2,'          ',F5.3,'
94:     C   ',F7.2,'/',F5.1,'   ',F5.2,'   ',F5.2,'    ',F5.2)
95:       ENCODE(96,500,ILA1)
96: 500 FORMAT('                            POSITION')
97:       CALL TEXTO(1,ILA1,24,3,1,1,3,IER)
98:       IF(IER.NE.0)OUTPUT(101) IER,'    POSITION'
99:       ENCODE(96,502,ILA2)
100: 502 FORMAT('              X           Y           ZZ         PSI
101:     CPHI       THETA')
102:       CALL TEXTO(1,ILA2,24,4,1,1,3,IER)
103:       ENCODE(96,505,ILA3)
104: 505 FORMAT('                            VELOCITY')
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105:        CALL TEXT0(1,ILA3,24,11,1,1,3,IER)
106:        IF(IER.NE.0)OUTPUT(101) IER, '    VELOCITY'
107:        ENCODE(96,517,ILA4)
108:  517 FORMAT('            U         V         W         R
109:     CP           G')
110:        CALL TEXT0(1,ILA4,24,12,1,1,3,IER)
111:        IF(IER.NE.0)OUTPUT(101) IER, '   LIST VAR VELOCITY'
112:        ENCODE(96,509,ILA5)
113:  509 FORMAT('                        ACCELERATION')
114:        CALL TEXT0(1,ILA5,24,19,1,1,3,IER)
115:        IF(IER.NE.0)OUTPUT(101) IER, '   ACCEL TITLE'
116:        ENCODE(96,512,ILA6)
117:  512 FORMAT('        UDOT       VDOT       WDOT      RDOT      PD
118:     OT      QDOT')
119:        CALL TEXT0(1,ILA6,24,20,1,1,3,IER)
120:        IF(IER.NE.0)OUTPUT(101) IER, '   ACCEL VAR'
121:        ENCODE(96,514,ILA7)
122:  514 FORMAT(' CONTROL INPUTS        TIME               NAV
123:     CIGATION DATA')
124:        CALL TEXT0(1,ILA7,24,27,1,1,3,IER)
125:        IF(IER.NE.0)OUTPUT(101) IER, '   CONTROL HEADING'
126:        ENCODE(96,515,ILA8)
127:  515 FORMAT('THRUST    RUDDER     DELT    ELAPSED     PITCH   HEADING/R
128:     OATE    DRIFT    ROLL    SPEED')
129:        CALL TEXT0(1,ILA8,24,28,1,1,3,IER)
130:        IF(IER.NE.0)OUTPUT(101) IER, '   SUB LABEL CONTROL'
131:        CALL WRITECLOCK(0)
132:        CALL STARTCLOCK
133:  101 CONTINUE
134:        CALL ADDA(AD,NAD,AA,NDA)
135:        CALL READCLOCK(N)
136:        CALL WRITECLOCK(0)
137:        X1=PSI/6.283185
138:        IX=X1
139:        AIX=X1-IX
140:        IF(AIX.LT.0.0)GO TO 10
141:        HEAD=AIX*360.
142:        GO TO 11
143:   10 AIX1=1.+AIX
144:        HEAD=AIX1*360.
145:   11 CONTINUE
146:        ARATE=(360.*R)/6.283185
147:        AROLL=(360.*PHI)/6.283185
148:        APITCH=(360.*THETA)/6.283185
149:        SPEED=U*.597213
150:        IF(H1.GT.X0)GO TO 700
151:        H1=X0
152:  700 IF(H2.GT.Y0)GO TO 701
153:        H2=Y0
154:  701 IF(H3.GT.ZZ)GO TO 702
155:        H3=ZZ
156:  702 IF(H4.GT.PSI)GO TO 703
157:        H4=PSI
```

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158:      703 IF(H5.GT.PHI)G9 T9 704
159:          H5=PHI
160:      704 IF(H6.GT.THETA)T9 T9 705
161:          H6=THETA
162:      705 IF(H7.GT.U)G9 T9 706
163:          H7=U
164:      706 IF(H8.GT.V)G9 T9 707
165:          H8=V
166:      707 IF(H9.GT.W)G9 T9 708
167:          H9=W
168:      708 IF(H10.GT.R)G9 T9 709
169:          H10=R
170:      709 IF(H11.GT.P)G9 T9 710
171:          H11=P
172:      710 IF(H12.GT.G)G9 T9 711
173:          H12=G
174:      711 IF(H13.GT.UD9T)G9 T9 712
175:          H13=UD9T
176:      712 IF(H14.GT.VD9T)T9 T9 713
177:          H14=VD9T
178:      713 IF(H15.GT.WD9T)T9 T9 714
179:          H15=WD9T
180:      714 IF(H16.GT.RD9T)G9 T9 715
181:          H16=RD9T
182:      715 IF(H17.GT.PD9T)G9 T9 716
183:          H17=PD9T
184:      716 IF(H18.GT.GD9T)T9 T9 718
185:          H18=GD9T
186:      718 IF(H30.LT.X0)G9 T9 719
187:          H30=X0
188:      719 IF(H31.LT.Y0)G9 T9 720
189:          H31=Y0
190:      720 IF(H32.LT.ZZ)G9 T9 721
191:          H32=ZZ
192:      721 IF(H33.LT.PSI)G9 T9 722
193:          H33=PSI
194:      722 IF(H34.LT.PHI)G9 T9 723
195:          H34=PHI
196:      723 IF(H35.LT.THETA)G9 T9 724
197:          H35=THETA
198:      724 IF(H36.LT.U)G9 T9 725
199:          H36=U
200:      725 IF(H37.LT.V)G9 T9 726
201:          H37=V
202:      726 IF(H38.LT.W)G9 T9 727
203:          H38=W
204:      727 IF(H39.LT.R)G9 T9 728
205:          H39=R
206:      728 IF(H40.LT.P)G9 T9 729
207:          H40=P
208:      729 IF(H41.LT.G)G9 T9 730
209:          H41=G
210:      730 IF(H42.LT.UD9T)G9 T9 731
```

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211:        H42=UD9T
212:    731 IF(H43.LT.VD9T)G9 T9 732
213:        H43=VD9T
214:    732 IF(H44.LT.WD9T)G9 T9 733
215:        H44=WD9T
216:    733 IF(H45.LT.RD9T)G9 T9 734
217:        H45=RD9T
218:    734 IF(H46.LT.PD9T)G9 T9 735
219:        H46=PD9T
220:    735 IF(H47.LT.QD9T)G9 T9 736
221:        H47=QD9T
222:    736 C9NTINUE
223:        DELT=(DELT+(N/60.))/2.
224:        TIME=TIME+DELT
225:    651 Z=0.5+A91
226:        IF(Z.GT..5)G9 T9 790
227:        IF(Z.LT.-.5)G9 T9 791
228:        IF(Z.GT..005)G9 T9 792
229:        IF(Z.LT.-.005)G9 T9 792
230:        Z=0.0
231:        G9 T9 792
232:    790 Z=.5
233:        G9 T9 792
234:    791 Z=-.5
235:        G9 T9 792
236:    792 C9NTINUE
237:        T=AT*A31*100.
238:        IF(T.GT.375.)G9 T9 793
239:        IF(T.LT.0.0)G9 T9 794
240:        G9 T9 795
241:    793 T=375.
242:        G9 T9 795
243:    794 T=0.0
244:        G9 T9 795
245:    795 C9NTINUE
246:    998 C9NTINUE
247:        PAAP=00.20*SIN(PSI)
248:        PHI=R
249:        THETA=UD9T
250:        W=PAAP
251:        P=PAAP
252:        G=PAAP
253:        WD9T=PAAP
254:        PD9T=PAAP
255:        QD9T=PAAP
256:        U=A11*X*AU
257:        V=A21*X*AV
258:        R=A31*X*AR
259:        UD9T=((-1.)*(CDX/180.)*U*J)+((T/180.)*C9S(Z))+V*R
260:        VD9T=((T/M)*SIN(Z))-((CDY/M)*V*ABS(V))-J*R
261:        RD9T=((CDY/IZ)*LW*V*ABS(V))-((T/IZ)*L9*SIN(Z))+(A22*J*V*(LW/IZ))
262:        BETA=ATAN(V/U)
263:        VS=((U*U)+(V*V))**.5
```

```
264:          PSI=PSI+DELT*R
265:          XODOT=U*COS(PSI)-V*SIN(PSI)
266:          YODOT=U*SIN(PSI)+V*COS(PSI).
*267:         XO=YO+DELT*XODOT
268:          YO=YO+DELT*YODOT
269:          B11=UDOT/(AUDOT*100.)
*270:         B21=VDOT/(AVDOT*100.)
271:          B31=RDOT/(ARDOT*100.)
272:          B71=XO/(AXO*100.)
273:          B81=YO/(AYO*100.)
274:          IF(SENSE SWITCH 1)102,105
275:     102  CALL HOLD
276:          CALL STOPCLOCK
277:          WRITE(6,100)LR,JD,TTO,TO,TBEAR,HEAD,ATVECO,CCC,TVEC
278:     100  FORMAT(9F9.4)
279:          CALL STARTCLOCK
280:          CALL COMPUTE
281:     105  CONTINUE
282:          IF(A101.GT.-0.6)GO TO 101
283:          ICO=ICO+1
284:          IF(ICO.EQ.1)GO TO 653
285:          IF(ICO.EQ.3)GO TO 653
286:          IF(ICO.EQ.15)GO TO 653
287:          IF(ICO.EQ.22)GO TO 653
288:          IF(ICO.EQ.29)GO TO 653
289:          IF(ICO.EQ.36)GO TO 653
290:          GO TO 107
291:     653  ENCODE(96,501,ILAP)YO,XO,ZZ,PSI,PHI,THETA
292:     600  CALL TEXTO(1,ILAP,24,6,1,1,3,IER)
293:          IF(IER.NE.0)OUTPUT(101) IER, '    PRESENT'
294:     107  IF(ICO.EQ.5)GO TO 108
295:          GO TO 109
296:     108  ENCODE(96,525,ILAP)H2,H1,H3,H4,H5,H6
297:          CALL TEXTO(1,ILAP,24,8,1,1,3,IER)
298:     109  IF(ICO.EQ.10)GO TO 110
299:          GO TO 111
300:     110  ENCODE(96,526,ILAP)H31,H30,H32,H33,H34,H35
301:          CALL TEXTO(1,ILAP,24,9,1,1,3,IER)
302:     111  IF(ICO.EQ.2)GO TO 601
303:          IF(ICO.EQ.9)GO TO 601
304:          IF(ICO.EQ.16)GO TO 601
305:          IF(ICO.EQ.23)GO TO 601
306:          IF(ICO.EQ.30)GO TO 601
307:          IF(ICO.EQ.37)GO TO 601
308:          GO TO 112
309:     601  ENCODE(96,507,ILAP)U,V,W,R,P,Q
310:          CALL TEXTO(1,ILAP,24,14,1,1,3,IER)
311:     112  IF(ICO.EQ.15)GO TO 113
312:          GO TO 114
*313:    113  ENCODE(96,527,ILAP)H7,H8,H9,H10,H11,H12
314:          CALL TEXTO(1,ILAP,24,16,1,1,3,IER)
315:     114  IF(ICO.EQ.20)GO TO 115
315:          GO TO 116
```

```
317:    115 ENCODE(96,528,ILAP)H36,H37,H38,H39,H40,H41
318:        CALL TEXTS(1,ILAP,24,17,1,1,3,IER)
319:    116 IF(IC9.EQ.3)G8 T8 604
320:        IF(IC9.EQ.10)G8 T8 604
321:        IF(IC9.EQ.17)G9 T9 604
322:        IF(IC9.EQ.24)G8 T9 604
323:        IF(IC9.EQ.31)G8 T9 604
324:        IF(IC9.EQ.38)G8 T9 604
325:        G8 T8 117
326:    604 ENCODE(96,511,ILAP)UD8T,VD8T,WD8T,RD8T,PD8T,QD8T
327:        CALL TEXTS(1,ILAP,24,22,1,1,3,IER)
328:    117 IF(IC8.EQ.25)G8 T9 118
329:        G9 T8 119
330:    118 ENCODE(96,529,ILAP)H13,H14,H15,H16,H17,H18
331:        CALL TEXTS(1,ILAP,24,24,1,1,3,IER)
332:    119 IF(IC8.EQ.30)G8 T9 120
333:        G8 T8 121
334:    120 ENCODE(96,530,ILAP)H42,H43,H44,H45,H46,H47
335:        CALL TEXTS(1,ILAP,24,25,1,1,3,IER)
336:    121 IF(IC9.EQ.4)G8 T8 602
337:        IF(IC8.EQ.11)G8 T9 602
338:        IF(IC9.EQ.18)G8 T9 602
339:        IF(IC9.EQ.25)G9 T9 602
340:        IF(IC9.EQ.32)G8 T9 602
341:        IF(IC9.EQ.39)G8 T9 602
342:        G8 T8 923
343:    602 ENCODE(96,516,ILAP)T,Z,DELT,TIME,APITCH,HEAD,ARATE,BETA,AROLL,SPEE
344:       CD
345:        CALL TEXTS(1,ILAP,24,30,1,1,3,IER)
346:    923 IF(A101.GT.-0.90)G9 T8 924
347:        U=0.
348:        V=0.
349:        W=0.
350:        R=0.
351:        P=0.
352:        Q=0.
353:        XO=0.
354:        YO=0.
355:        ZZ=0.
356:        PSI=0.
357:        PHI=0.
358:        THETA=0.
359:        UD8T=0.
360:        VD8T=0.
361:        WD8T=0.
362:        RD8T=0.
363:        PD8T=0.
364:        QD8T=0.
365:        TIME=0.
366:        H1=0.
367:        H2=0.
368:        H3=0.
369:        H4=0.
```

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370:          H5=0.
371:          H6=0.
372:          H7=0.
373:          H8=0.
374:          H9=0.
375:          H10=0.
376:          H11=0.
377:          H12=0.
378:          H13=0.
379:          H14=0.
380:          H15=0.
381:          H16=0.
382:          H17=0.
383:          H18=0.
384:          H30=0.
385:          H31=0.
386:          H32=0.
387:          H33=0.
388:          H34=0.
389:          H35=0.
390:          H36=0.
391:          H37=0.
392:          H38=0.
393:          H39=0.
394:          H40=0.
395:          H41=0.
396:          H42=0.
397:          H43=0.
398:          H44=0.
399:          H45=0.
400:          H46=0.
401:          H47=0.
402:     924  CONTINUE
403:          IF(ICA.EQ.5)GO TO 603
404:          IF(ICA.EQ.12)GO TO 603
405:          IF(ICA.EQ.19)GO TO 603
406:          IF(ICA.EQ.26)GO TO 603
407:          IF(ICA.EQ.33)GO TO 603
408:          IF(ICA.EQ.40)GO TO 603
409:          GO TO 610
410:     603  CONTINUE
411:     59   CONTINUE
412:          X1X=.45*COS(PHI)
413:          Y1Y=.45*SIN(PHI)
414:          X1XA=(2.5*R)+X1X
415:          X11=2.5*R
416:          Y1YA=THETA-Y1Y
417:          X1XB=(2.5*R)-X1X
418:          Y1YB=THETA+Y1Y
419:          X1XC=(2.5*R)+(0.1*SIN(PHI))
420:          Y1YC=THETA+(0.1*COS(PHI))
421:          ICAA=ICAA+1+(1.*U)+(10.*(ICAA/514.))
422:          Y1YD=(ICAA/514.)*(-1.0)+(THETA)-0.1+
```

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423:        Y1YE=(IC8A/514.)*(-1.0)+(THETA)-0.14
424:        X1XD=(X1XB-0.05)-((IC8A/514.)*0.2)
425:        X1XE=X1XB-0.05
426:        X1XF=X1XA+0.05
427:        X1XG=(X1XA+0.05)+((IC8A/514.)*0.2)
428:        Y1YR=Y1YA-0.14
429:        Y1YL=Y1YB-0.14
430:        H=(0.2/COS(PHI))
431:        H1=H*SIN(PHI)
432:        Y1YEE=Y1YE-(IC8A/2700.)
433:        REARA1=-0.5
434:        REARA2=-0.5+Y1Y
435:        REARB1=-0.5
436:        REARB2=-0.64++Y1Y
437:        REARC1=0.5
438:        REARC2=-0.5-Y1Y
439:        REARD1=0.5
440:        REARD2=-0.64-Y1Y
441:   65   SESX=0.75+(Y0/5000.)
442:        SESY=0.75+(X0/5000.)
443:        IF(Y1YE.GT.-0.6)G0 T0 59
444:        IC8A=0
445:   59   CONTINUE
446:        IVIEWA(1)=IHEAD(0,10)
447:        IVIEWA(2)=IPACK(REARA1,REARA2,0)
448:        IVIEWA(3)=IPACK(X1XB,Y1YB,1)
449:        IVIEWA(4)=IPACK(X1XA,Y1YA,1)
450:        IVIEWA(5)=IPACK(REARC1,REARC2,1)
451:        IVIEWA(6)=IPACK(REARA1,REARA2,1)
452:        IVIEWA(7)=IPACK(REARB1,REARB2,1)
453:        IVIEWA(8)=IPACK(REARD1,REARD2,1)
454:        IVIEWA(9)=IPACK(REARC1,REARC2,1)
455:        IF(R.GT..02)G0 T0 50
456:        IF(R.LT.-.02)G0 T0 51
457:        IVIEWA(10)=IPACK(X1XD,Y1YEE,0)
458:        IVIEWA(11)=IPACK(X1XE,Y1YE,1)
459:        IVIEWA(12)=IPACK(X1XF,Y1YE,0)
460:        IVIEWA(13)=IPACK(X1XG,Y1YEE,1)
461:        IVIEWA(14)=IPACK(0.0,0.0,0)
462:        G0 T0 55
463:   50   IVIEWA(10)=IPACK(X1XA,Y1YA,0)
464:        IVIEWA(11)=IPACK(X1XA,Y1YR,1)
465:        IVIEWA(12)=IPACK(REARD1,REARD2,1)
466:        IVIEWA(13)=IPACK(X1XF,Y1YE,0)
467:        IVIEWA(14)=IPACK(X1XG,Y1YEE,1)
468:        G0 T0 55
469:   51   IVIEWA(10)=IPACK(X1XB,Y1YB,0)
470:        IVIEWA(11)=IPACK(X1XB,Y1YL,1)
471:        IVIEWA(12)=IPACK(REARB1,REARB2,1)
472:        IVIEWA(13)=IPACK(X1XE,Y1YE,0)
473:        IVIEWA(14)=IPACK(X1XD,Y1YEE,1)
474:        G0 T0 55
475:   55   CONTINUE
```

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476:        IVIEWA(15)=IPACK(SESX,SESY,0)
477:        IVIEWA(16)=IPACK(SESX,SESY,1)
478:        IVIEWA(17)=0
479:        CALL GRAPHØ(2,IVIEWA,17,2,IER)
480:  610   IF(ICØ.LE.40)GØ TØ 101
481:        ICØ=0
482:        GØ TØ 101
483:        END
```

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